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ABSTRACT

A specific teaching strategy to effect conceptual change used with a single class of fifth grade students was evaluated. The Rand McNally SCIIS "Communities" unit used in this study can be characterized as a conceptual change strategy because it is organized around a three-phase learning cycle designed to move students from preconceptions to new, more scientific concepts. The three phases include exploration, invention, and discovery. Data were collected on the students' conceptual knowledge and their experience of instruction. Pretests and posttests were given to distinguish among alternative conceptions of plants' source of food and the role of light in plant growth. Lessons in the instructional unit were observed and recorded. The impact of instruction on students was similar to a previous study; only one student appeared to hold the intended goal conception with the others retaining their preconceptions or various hybrid conceptions. The contrast between these results and the reasonableness of the SCIIS strategy led the authors to examine several problems which appear to have general implications for cognitive instruction. In this report, the nature of these problems is documented and described, and their implications for teaching, curriculum development, and research are discussed. (DWH)

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Vol. II

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WAYS OF GOING WRONG IN TEACHING FOR CONCEPTUAL CHANGE: REPORT ON THE CONCEPTUAL CHANGE PROJECT*

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As reflected in the research reported at a recent international conference devoted to student misconceptions in science and mathematics (Helm and Novak, 1983), it is now well established that students generally possess conceptions relevant to curricular topics before they begin study of them. It is further clear that such preconceptions often persist despite instruction on scientific theories which contradict them. The discrepancies between the students' post instruction conceptions and the scientific theories as taught often represent important failures of instruction.

Viennot (1979) among others has argued that students' preconceptions persist in part because they have worked so well in the everyday world of students. That similar ideas have sometimes held sway among scientists for centuries is testimony to their explanatory power. Anderson and Smith (1983b) described how preconceptions are often compatible with much of the student's experience of instruction. Thus, preconceptions are active competitors with scientific alternatives as organizing structures for students experience of instruction as well as for their everyday experience.

The existence and persistence of students preconceptions implies that learning involves not simply the acquisition or formation of new concepts. It involves the modification of existing concepts or their replacement with appropriate alternatives, i.e., conceptual change (Toulmin, 1972).

Several researchers have proposed models of conceptual change. Posner, Strike, Hewson and Gertzog (1982) propose four conditions that must be fulfilled if accommodation* is likely to occur, that is, if students are to make

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*Both Posner, et al., (1982) and Nussbaum and Novick (1982a,b) use the term accommodation to refer to instances where students central conceptions undergo change in contrast to instances in which new information is incorporated with existing conceptions with little change (assimilation).

changes in their central concepts:

1. There must be dissatisfaction with existing conceptions.
2. A new conception must be intelligible.
3. A new conception must be initially plausible.
4. A new conception should appear fruitful (lead to new insights and discoveries).

Nussbaum and Novick (1982a,b) describe a general teaching strategy for use where significant accommodation is expected.

1. Initial exposure of students' alternative conceptions through their responses to an "exposing event;"
2. Sharpening student awareness of their own and other students' alternative conceptions, through discussion and debate;
3. Creating conceptual conflict by having the students attempt to explain a discrepant event;
4. Encouraging and guiding cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception.

In one study Nussbaum and Novick (1982b) applied their model to the development and assessment of an instructional strategy designed to promote specific changes in sixth grade students' conceptions of the nature of gases. The authors reported that the strategy was "highly efficient in creating cognitive challenge and motivation for learning," but "did not lead to the desired total conceptual change in all students." In fact only one of the seventeen students was reported to have adopted the intended goal conception. The others ended up with one of five conceptions the investigators identified as intermediate between the students' original preconception and the goal conception. Another five students progressed as far as the last intermediate conception. The remaining students, about two-thirds, completed instruction with several misconceptions. The major conclusion drawn by the authors was

"that a major conceptual change does not occur, even with good instruction, through revolution but is by nature an evolutionary process."

Overview of the Study and Report

In many respects the present study was similar to that of Nussbaum and Novick (1982b). It was a case study of the use of a particular teaching strategy with a single class of fifth-graders. Our data sources included pre and posttest responses for all students, interviews of target students at five different points, observation notes and narrative descriptions of instruction, tape recordings of all lessons, and transcripts of selected class discussions. In the study we analyzed the changes that did (and did not) occur in the conceptions of the students as they experienced instruction designed to change their conceptions of how green plants get their food. The instruction was based on Chapters 3-6 of the Rand McNally SCIIS Communities unit (Knott, Lawson, Karplus, Thier and Montgomery, 1978). This sequence incorporates elements of the conceptual change models summarized above.

One difference between the Nussbaum and Novick study and ours was that, in our study, the teacher was an experienced elementary teacher teaching her own students without direct input from the researchers. She was teaching the sequence for the third year, this time using a teacher's guide developed in a related study (Smith and Anderson, 1983a) and designed to make the conceptual change strategy more explicit.

The impact of instruction on students in our study was similar to that reported by Nussbaum and Novick (1982b). Following instruction only one student appeared to hold the intended goal conception with the others retaining their preconceptions or various hybrid conceptions. Similar results were obtained with a larger sample in a related study (Roth, Smith and Anderson, 1983).

While our results are consistent with those reported by Nussbaum and Novick (1983b), there seemed to be another story in our study, one concerned with ways that instruction seemed to go wrong where it might have been otherwise. While these problems may not have occurred in Nussbaum and Novick's study, it is important to consider carefully the adequacy of instruction and of the particular instructional strategy in making judgments about a generic strategy and its theoretical base. The contrast between our results and the reasonableness of the SCIIS strategy led us to examine the issue of what went wrong. We were led to a number of problems that appear to have general implications for cognitive instruction. Among these were:

- Students were often uncertain about empirical generalizations important to the strategy.
- Communication was sometimes hampered by systematic sources of ambiguity.
- Some important issues were not adequately framed through use of appropriate questions.
- The instruction was in some ways attacking the wrong preconception.

In this report we document and describe the nature of these problems and discuss their implications for teaching, curriculum development and research.

This report also includes a summary of the methods employed in the project, a description of the instructional strategy for the instructional sequence investigated, and a summary of the group results on the pre and post-tests. Further documentation of the project is available in a series of progress reports. Additional publications are planned to report other aspects of the project.

Methods

Data Source

The study was conducted with one of three groups of fifth-grade students in one of eight elementary schools in a predominantly middle class school district. The class included some children of working class and professional parents and a minority of Black children.

The teacher was an experienced elementary teacher who taught science to all three groups of fifth graders in a team teaching situation. She was teaching the Communities unit for the third year. She had participated in a related study (Smith and Anderson, 1983a) the previous year and had been among the more successful of the nine teachers observed, although none of those teachers had been very successful in bringing about changes in their students conceptions of plants sources of food. As a result of her continued participation in the related study, she was using a teachers guide designed to make the conceptual change aspects of the instruction more explicit than they had been in the SCIIS guide. The teaching suggestions themselves remained essentially unchanged, however.

Data Collection

Data were collected on the students' conceptual knowledge and their experience of instruction. Before and after instruction the entire class was administered a test designed to distinguish among alternative conceptions of plants source of food and the role of light in plant growth. The test included multiple choice and true-false items as well as questions requiring written answers. This test and the analysis procedures are described elsewhere (Roth, Smith and Anderson, 1983). Briefly, the students' responses were first coded using defined features of the responses. These codings were

then used to compute scores reflecting the amount of evidence supporting inferences of student belief in alternative propositions and interrelated sets of propositions or conceptions. Students for whom evidence was contradictory were classified as indeterminate with respect to the topic involved.

In addition to the test, four students were interviewed before and after instruction and at three points during the period of instruction. Each interview presented the students with relevant situations and asked for predictions and explanations of what would happen. The interviews during the period of instruction included predictions and explanations concerning the investigations conducted as part of the instruction. These interviews thus provided information about the students' interpretation of instruction as well as their conceptions.

Each lesson was observed and recorded. The observer made notes emphasizing nonverbal behavior and focusing on the four target students. Two tape recordings were made, one using a directional microphone located above the target group and the other oriented to pick up the whole class and especially the teacher. Lessons anticipated as being especially important, beginning or concluding an investigation, for example, were also observed by a second observer and/or video recorded.

The observation notes and tape recordings were used to prepare written narratives describing the instruction. This process included breaking the lessons down into segments corresponding to the tasks in which students were to be engaged. Further analysis was organized in terms of the lesson and task structure of the instruction.

Analysis

The analysis was organized into two phases. During Phase I, the tests, interviews and lessons were reviewed and the propositional content identified.

The Phase I analysis was designed to tentatively identify important changes in student conceptions and identify lessons and tasks containing information relevant to those changes. These changes and the related segments of instruction became the foci for analysis in Phase II.

This Phase I analysis was organized and carried out using a master list of proposition frames. These frames specified certain components of a proposition that were fixed and others that could vary. Any proposition that reflected the constant portion of the proposition frame was considered an alternative instantiation of that frame. Codes for the alternative propositions thus defined were designated. For example, the following frame deals with the relationship between the continuing growth of plants and the conditions of light:

Proposition Frame	Options	
Plants (do/do not) continue to grow in (condition: light/dark)	A. Do, light B. Do not, dark	1. Do, only in light
	K. Do not, light L. Do, dark	2. Do, in light or dark

The numbered options represent more comprehensive propositions, reflecting combinations of the component propositions represented by letters. The number 1 and letters A-J designate goal propositions, while other numbers and the letters K-U designate alternative ones.

The Phase II analyses were guided by Phase I results, but used transcripts of interviews and relevant portions of lessons as primary sources. The analysis reported here drew primarily on the lesson transcripts and group pre/posttest data. In particular, the analysis focused on what happened in instruction with respect to the questions, anticipated results and presentations constituting the instructional strategy. As background for the presentation of results, the instructional strategy is presented next.

Instructional Strategy

In the introduction we asserted that the sequence from the SCIIS Communities Unit was a conceptual change strategy. This assertion is based in part on the authors' explicit definition and discussion of the SCIIS Learning Cycle but also on our interpretation of the specific teaching suggestions in the Communities teacher guide (Knott, et al., 1978).

The SCIIS Learning Cycle

According to the teacher's guide, the SCIIS curriculum is organized around a "learning cycle" consisting of three phases: exploration, invention and discovery. Exploration is characterized as involving students in "spontaneous handling and experimenting with objects to see what happens." The guide points out that "the materials have been carefully chosen to provide a background for certain questions the children have not asked before." It further notes, "During exploration activities you have the opportunity to observe the children and draw conclusions about their existing ideas and understandings" (Ibid, p. xviii). This implies that the exploration phase includes something like the "exposing events" advocated by Nussbaum and Novick (1982a). The guide's description of the Learning Cycle does not mention anything like Nussbaum and Novick's "discrepant events," but as will be seen below, the strategy for the sequence under investigation does include and make use of such events.

The second phase of the SCIIS Learning Cycle is invention. This is the introduction by the teacher of a new concept as an alternative to the "preconceptions" which limit students' "spontaneous learning." The teacher 'will have to provide definitions and terms as new concepts arise. This constitutes the "invention"' (Knott, et al., 1978, p. xviii). Further insight into the

intended nature of the "invention" is provided in an article coauthored by the director of the original SCIS project, Robert Karplus, (Atkin and Karplus, 1962). While students are viewed as able to "invent concepts readily," they are not viewed as likely to be "able to invent the modern scientific concepts..." thus "it is necessary for the teachers to introduce them" (Ibid, p. 47). The authors related this idea to the view that science itself progresses through the invention of new concepts which are not only more powerful and useful, but which change the meaning and interpretation of observations. Thomas Khun's classic articulation of this view (1962) was cited in the article.

Following the invention of a new concept comes the discovery stage. It is important to note that it is not the new concept which is discovered, that is what is invented (i.e., presented by the teacher). Rather, this stage consists of "...activities in which a child finds a new application of a concept through experience" (Knott, et al., 1978, p. xviii). The students have opportunities "to discover that new observations can also be interpreted by using (the new) concept" (Atkin and Karplus, 1962, p. 47). Such activities "strengthen the concept and expand its meaning" (Knott, et al., 1978, p. xviii). They are "essential, if a concept is to be used with increasing refinement and precision" (Atkin and Karplus, 1962, p. 47).

The Instructional Sequence: SCIIS Chapters 3-6

The SCIIS Learning Cycle is designed to move students from preconceptions to new, more scientific concepts and can, therefore, be characterized as a conceptual change strategy. Further, the four-chapter sequence on which our research has focused includes elements similar to the exposing and discrepant events emphasized by Nussbaum and Novick (1982a,b).

The instructional sequence consists of four chapters (3-6) from the SCIIS Communities unit and represents about six weeks of instruction with about three lessons per week. The strategy for the unit is represented in Table 1 as a series of questions, anticipated empirical results of student investigations, and teacher presentations. The major presentation is the invention of the concept of photosynthesis at the end of Chapter 5.

Although not initially apparent, the underlying issue for the sequence is the source of food for plants. Following the student's introduction to the parts of the bean seeds in Chapter 3, Question 2 raises the issue of the function of the seed parts. This focus, carried on through Chapter 4, is crucial since the cotyledon's function of providing food to the embryo is intended to lead into the central, underlying issue of the source of food for plants. Raised again in Question 6 this issue leads the interpretation of the investigation in Chapter 4 beyond the essentially empirical generalization that the cotyledon and embryo need each other for a new plant to grow with which the discussion might otherwise conclude.

Questions 7 and 14 are important in exposing students' preconceptions about the relationship of light to plant growth and the sources of food for plants, respectively. Question 15 is the point at which the anticipated student preconception that plants get their food from the soil is to be confronted with the discrepancy of plants dying in the dark despite the presence of rich soil. This concludes the exploration phase of the sequence.

Following the invention of photosynthesis as an alternative conception of plants source of food, Question 16 leads to the application of the new concept in explaining the results obtained. Chapter 6 is the discovery phase of the sequence in which the concepts of photosynthesis and the food supplying function of the cotyledon are to be applied in predicting and explaining continued

TABLE 1

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS COMMUNITIES

Anticipated Preconceptions	Strategy Elements: Framing Question	Empirical Results	Presented Information	Intended New Conceptions
	Exploration Phase of the Learning Cycle			
	Chapter 3: Looking at Seeds			
	1. What is inside seeds?	Bean seeds have a small, plant-like part inside two larger halves and a skin.	The small plant-like part is the "embryo," the two halves are "cotyledons."	Seeds have a small, plant-like part--the embryo--and larger part(s)--the cotyledons.
	2. What do the embryo and cotyledon do for the growing plant?			
	Chapter 4: What Seed Parts Develop and Grow			
Plants take in their food from the soil.	3. What seed parts develop and grow? What do you think each part of the seed does?	Bean embryos develop into plants only when attached to a cotyledon.		
Water, fertilizer and minerals are food for plants.	4. Why did the cotyledon and embryo live when joined?			The embryo develops into a new plant. The embryo develops into a plant only if it is attached to a cotyledon. The cotyledon provides food for the embryo.
	5. Why didn't the cotyledon or embryo grow alone?			
	6. What do the embryo and cotyledon do for the plant?			

TABLE 1 (Continued)

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS COMMUNITIES

Anticipated Preconceptions	Strategy Elements: Framing Question	Empirical Results	Presented Information	Intended New Conceptions
	Chapter 5: Do Plants Need Light to Grow?			
Plants need light to live and grow.	7. Do plants need light to grow? When?	Grass begins to grow in the dark and in light.		
	8. Why are the plants in the dark growing so well?			Plants do not need light to begin to grow.
	9. Which plants will survive better? Why?			
	10. How could you make the yellow grass turn green and the green grass turn yellow?			Plants get food from their seeds (cotyledons)
	11. What has happened to the grass set ups?	Grass continues to grow in the light but not in the dark.		
	12. What does light do for plants?			
	13. Why did the plants grow in the dark for awhile?			Plants do need light to continue to grow.
	14. Where do plants get the food they need?			
	15. Why did the plants in the dark die and those in the light live when both had the same soil?			
	Invention Phase of the Learning Cycle			
	16. Can you explain the results using the idea of photosynthesis?	Plants use energy from light to make food from water and air.		Plants use light to make food out of water and air.

TABLE 1 (Continued)

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS COMMUNITIES

Anticipated Preconceptions	Strategy Elements: Framing Question	Empirical Results	Presented Information	Intended New Conceptions
	Discovery Phase of Learning Cycle			
	Chapter 6: Cotyledons			
	17. What do you think will happen to young bean plants with and without cotyledons placed in the light and dark, respectively? Explain your reasons.	Bean plants without cotyledons grow in light, but die in the dark. Bean plants with cotyledons continue to grow in light, but stop growing in dark after the cotyledons shrivel and fall off.		
	18. Which grew better--plants with or without cotyledons?			
	19. How well did plants without cotyledons grow in the dark? In the light?			
	20. What do you think the cotyledons do for a young plant?			The cotyledon provides food for young plants. After the food from the cotyledon is gone, plants need light to make their food.
	21. When do plants need light?			

growth of bean seedlings with cotyledons removed and left on under conditions of light and darkness, respectively.

Student Learning Results

The major goal of the instructional sequence investigated is to challenge the anticipated students' prior belief that plants get food from the soil and develop the alternative conception that plants make their food and require light to do so. This conception is to serve as a foundation for the concept of a biological community and plants' unique role as "producers"--organisms which use light to make food that ultimately supports all of the other organisms (Knott, et al., 1978).

Group data reflecting changes in students' conceptions of plants sources of food and the role of light in plant growth were obtained using a test developed and used in a related study (Roth, Smith and Anderson, 1983). In general, the test results in the present study were similar to those obtained on a larger sample in the earlier study. As reflected in Table 2, there was some movement toward the goal conception of plants source of food. However, only one student appeared to have completed the intended changes.

As anticipated in the SCIIS teacher's guide (Knott, et al., 1978), most of the students consistently asserted on the pretest that plants take in food from the soil, water and/or air in their surroundings (Table 2). Many of the students were initially uncertain about the issue of plants making food. The few (3) who consistently asserted on the pretest that plants do make food did not relate this source of food to light (Table 3). On the posttest, nearly half of the students still consistently asserted that plants take in food (Table 2). All but one of the rest reflected uncertainty on this issue. While about half of the students consistently asserted that plants make food, only three related this to the presence of light (Table 3).

TABLE 2

CHANGES IN STUDENTS CONCEPTIONS
OF THE SOURCE OF FOOD FOR PLANTS*

Pretest

Make food \ Take in Food	do	?	do not	Row Totals
do not	5	0	0	5
?	9	4	0	13
do	3	0	0	3
Col. totals	17	4	0	21

Posttest

Make food \ Take in food	do	?	do not	Row Totals
do not	2	3	0	5
?	4	2	0	6
do	4	5	1	10
Col. totals	10	10	1	21

*The intended learning is reflected in movement of students from the upper left to the lower right in the table. Data are the numbers of students. Based on proposition scores I and M.

These data indicate that by-and-large the instruction failed to bring about the intended changes in students' conceptions of the source of food for plants. However, the results also indicate that many of the students did not understand an important empirical relationship on which the instructional depends. The strategy builds on the anticipated results that plants left in the dark "died" while those in the light "turned green and grew," despite the fact that "the soil was the same in every cup" (Knott, et al., 1978, p. 23). This result is intended as the major challenge to the students' preconception that plants get their food from the soil. The posttest indicated, however, that this result was not apparent to many of the students.

On the posttest, only about half of the students consistently asserted that plants would continue to grow only if they had access to light (Table 4).

TABLE 3

STUDENT CONCEPTIONS OF THE RELATION OF LIGHT TO PLANTS MAKING FOOD*

	Pretest f	Pretest %	Posttest f	Posttest %
1. Plants make food using light, air, water	0	0	1	5
2. Plants make food only in the light	0	0	2	10
3. Plants make food in light and dark	1	5	2	10
4. Plants make food only in the dark or unsure about relation to light	2	10	5	24
5. Plants do not make food	5	24	5	24
6. Uncertain whether plants make food	13	62	6	29

*Based on proposition scores I, LA, LB, K1 and K3.

TABLE 4

STUDENT CONCEPTIONS OF THE RELATIONSHIP BETWEEN LIGHT AND PLANT GROWTH*

	Pretest f	Pretest %	Posttest f	Posttest %
Plants begin to grow in light or dark but continue to grow only in light	2	10	11	52
Plants grow only in light	12	57	0	0
Plants grow in light or dark but are shorter/less healthy/not green in the dark	0	0	2	10
Plants grow in light or dark	1	5	4	19
Uncertain/inconsistent responses	6	29	4	19

*Based on responses to items 1.03, 1.05, 2.03 and 3.24-5.

Nearly half apparently ended up either believing that plants do not need light to survive or uncertain about this relationship. The sources and consequences of this ambiguity are central issues in the analysis reported in the next section.

Analysis of Actual Instruction: Some Ways of Going Wrong

As stated in the introduction, the limited attainment of the intended learning goals despite the apparent reasonableness of the SCIIS strategy led us to examine the issue of what went wrong. A previous study found that teachers often omitted critical elements of the instructional strategy (Smith and Anderson, 1983a; Smith and Anderson, 1983b). However, this was not so in the present case. Thus, our analysis focused on the way in which the strategy elements were implemented and the ways the students responded.

In this section we document and describe four aspects of instruction which help explain the disappointing learning results in the present study: empirical ambiguity, ambiguity in discourse, loose framing of important issues, and inadequacy in formulation of the preconception that the instructional strategy is designed to attack.

Empirical Ambiguity

As noted above the problems in student learning were not limited to the more abstract issues of plants sources of food and the function of light in plant growth. Many students also reflected misconceptions or uncertainty about the empirical results.

The instructional strategy depends on certain empirical generalizations. For example, Chapter 4 addresses the issue of the functions of parts of seeds and involves an experiment in which students attempt to germinate four different combinations of bean seed parts as shown below:

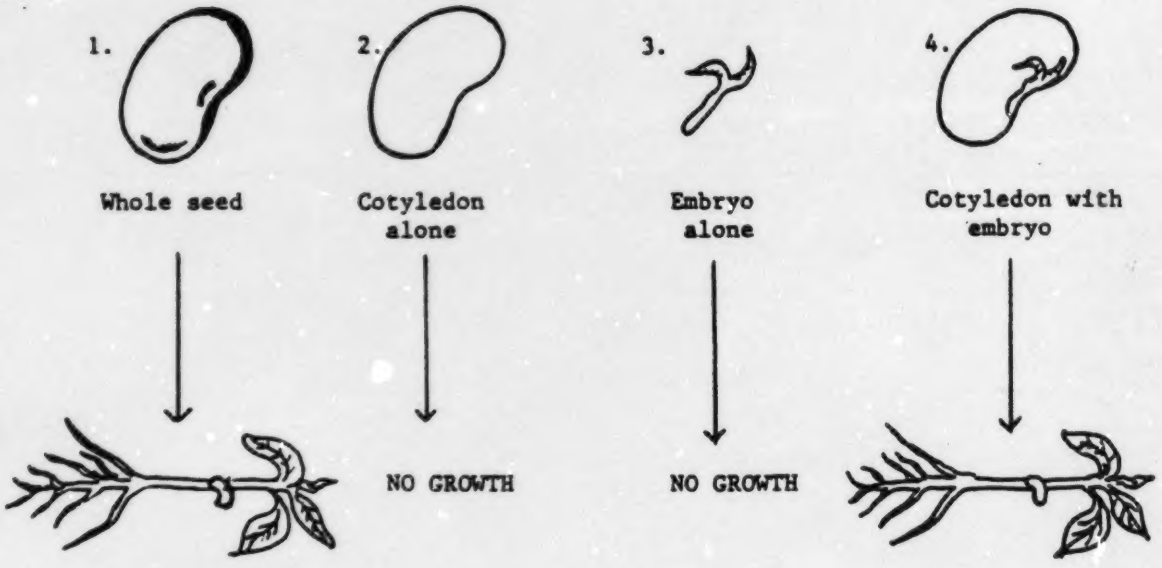

Figure 1. The four conditions for the experiment in Chapter 4 and the anticipated results.

Development of ideas about seed part functions uses the generalization that the embryo develops into a plant only if attached to a cotyledon. This generalization in turn rests on the anticipated results that neither the isolated embryos nor the isolated cotyledons grow, while the embryos with one cotyledon attached and the whole seeds do grow as illustrated. From the standpoint of a trained adult these trends were clear in the students' results. However, making the intended empirical generalization was not a straightforward matter for many of the students

Two sources of difficulty relate to aspects of what Strike and Posner (1982) refer to as the students' conceptual ecology, namely their implicit measurement and observation theories. First, some of the students attended primarily to their own individual set up, ignoring other instances. Their implicit assumption seems to have been that one case is sufficient and agreement among multiple instances is irrelevant. Thus, atypical results obtained by

some groups were sometimes generalized even when the trend across groups was clearly in the opposite direction.

For example, in some instances the whole seeds did not germinate. The following excerpt from an interview of one of the target students following completion of Chapter 4 illustrates:

I: What did you think about the whole seed?

S: O.K., it went to 18 millimeters, and 19, 19, 20, 20. I don't know what happened. Well, the whole seed has everything right but it just didn't grow that much.

I: Do you think that some other whole seeds would grow or don't you think that any of the whole seeds grow?

S: I think that maybe some of them would. I don't know.

I: Did some of the other students' whole seeds grow?

S: I don't think so...

This is surprising because, as she implied, this results is somewhat counter intuitive. Furthermore, she had just correctly explained the meaning of points on the class chart which had color coded dots showing that some of the whole seeds had indeed grown substantially. Apparently, she had not felt it necessary or important to consider the other groups' results. Another indication of this assumption was students referring to atypical individual points on the class graph, rather than to some more central or representative point.

A second aspect of students' implicit observation theories that came into play was judging the significance of differences in the measurements. How much change in the length of the isolated embryo, for example, constitutes "growth." Some of these embryos did grow a few millimeters in length. In comparison to those attached to the cotyledons, however, this growth would generally be considered by our trained adults as negligible. On several occasions, however, students apparently did not apply the negligibility principle and reported that their isolated embryos "grew."

Some of these problems might have been overcome had the teacher put more emphasis on the class graph. That is, she might have pressed the students toward an alternative observation theory. However, the somewhat cumbersome procedure suggested for estimating, recording and connecting average points for each observation of each experimental condition was carried out for only some of the data. The combination of the relatively large amount of time and effort involved and the apparent greater meaningfulness to the students of actual example germination systems led her to deemphasize use of the class graph. Given the nature of the students' implicit observation theories, this appears to have contributed to the students continuing to use their original observation theories and the resulting ambiguity of the students' thinking concerning the empirical results.

The problem of ambiguity in the empirical results is even more serious in Chapters 5 and 6 where the issue is the role of light in plant growth. The stragety (see Table 1) depends on the generalization that plants continue to grow only in the light. That is, plants kept in the dark eventually stop growing and die, while plants kept in the light continue to live and grow. The data indicate, however, that student opinion moved in the opposite direction from pretest to posttest (see Table 4).

Part of the ambiguity lay in the results actually obtained. In the instruction for Chapter 5, the grass kept in the dark was initially yellow and tended to get lighter in color as the experiment progressed. The blades were also thinner and less erect than that in the light. However, the grass in the dark grew taller than that in the light and during the experiment did not turn completely brown and dry up as one might have expected.

In addition to the lack of more extreme symptoms of the eminent demise of the grass in the dark, only three of the ten samples of grass were actually

left in the dark during the entire investigation. As suggested in the teacher's guide, others were moved from the dark to the light and from the light to the dark. The symptoms of these plants were even less extreme. The tendency noted above of students to attend primarily to their own individual result rather than to look for trends across groups further limited the data base for the students. Thus, for most of the students the salient observations were the more rapid growth of the grass in the dark and the clear differences in color. These observations were consistent with a view that light was needed only for good color or health and several students made analogies with humans getting suntans and being healthier if they got sun.

As with Chapter 4, the ambiguity in the actual results in Chapter 5 was exacerbated by ambiguity in discussions and a degree of looseness in the framing of these issues. Of particular significance was the issue of the plants' survival. This will be considered in the subsequent sections.

Ambiguity in Discourse

The ambiguity just discussed in regard to empirical results may tend to arise to some degree in any instruction which relies on first hand inquiry. However, systematic ambiguity can also occur in classroom discourse. In the present case, such ambiguity exacerbated the empirical ambiguities described above.

The ambiguity in discussion of Chapter 4 arose from the possible alternative referents for the terms 'embryo' and 'cotyledon.' The issue underlying the investigation was the function of the embryo and cotyledon as parts of a seed. However, the experiment was set up with an isolated embryo and an isolated cotyledon as well as combinations of these parts (see Figure 1). Thus, the question, "Does the embryo grow?" is ambiguous. While the isolated

embryos did not grow, the embryos as parts attached to cotyledons did grow. Since the function of the embryo as the part that grows is a central issue, there were many opportunities for confusion during class discussions.

Similarly, an important observation made by one of the students and emphasized by the teacher was that the cotyledon (part) was shriveling or shrinking as the attached embryo grew. This was very suggestive of the cotyledon somehow being used up. However, some of the students interpreted these reports as referring to the isolated cotyledons (condition) and tended to disagree. In the process they did not attend to and have the benefit of this important but subtle observation.

In Chapters 5 and 6 a similar ambiguity arose in the use of the term 'grow.' The question, "Do plants need light to grow?" is ambiguous unless the time period or stage of development of the plant is specified. While initial growth of seeds can take place without light, continued growth and survival do require light.

The teacher perceived the inherent ambiguity and attempted to resolve it. However, rather than making the time period explicit in each case the teacher adopted a convention of using the term 'grow' to refer to beginning growth or germination and the term 'survival' to refer to continued growth. For example, in the last lesson (6.7), a student expressed his opinion about plants growing in a dark mine:

59 David: It's (light) not unimportant but you (plants) don't have to have it.

60 Ms. Kain: I think we did decide that we (plants) don't have to have light to grow, but we're talking about surviving, aren't we.

The teacher reflected the stipulated use of the term 'grow' here and again later when she responded to another student:

70 Ms. Kain: Yeah, we know that, don't we. The ones in the dark will grow.

But, as indicated in the following response of a student who appears to understand the relation of light to plant growth, student use of the term 'grow' does not always conform to this stipulation:

78 Julie: (Reading her answer to the question about seeds in a dark mine from her student manual) No. The seeds will grow at first but, unless it gets some light, it won't grow.

Thus, despite the teacher's effort the ambiguity remained and may even have been increased by the unusual restriction in meaning of a common word. It is clear how this may well have contributed to student misconceptions or uncertainty concerning the relation of light to plant growth.

Loose Framing of Important Issues

Many steps in the instructional strategy take the form of questions as reflected in Table 1. In a number of instances we observed problems that could have been lessened by more appropriate use of questions in framing the issues. For example, in Chapter 4 the students appeared to have considerable difficulty relating the empirical results of the investigation to the issue of the function of the seed parts. While part of the problem was probably the uncertainty of the students concerning the empirical results discussed above, another factor was the pattern of questions used to frame the investigation and the interpretation of results.

The strategy suggests introducing the investigation with a discussion of the students' ideas about the seed part functions. However, it includes no question requiring the students to use those ideas in predicting what might happen in the germination experiment. In actual instruction, no question

which would drive students' thinking to consider the relationship between the results and the students' ideas about the seed parts functions was posed prior to the last two of the six lessons for Chapter 4.

When the issue of the relationship between the results and the students' ideas about the seed parts functions was raised in lesson 5, the questions in terms of which it was framed appeared to be inadequate. The teacher asked the students what they thought the parts' functions were and for "evidence" to support their views. However, fewer than a quarter of the twenty-six responses drew on the results for the four conditions in the experiment. Apparently, the students' ideas about what would constitute evidence were such that they did not usually see the question as pointing them toward the results of the experiment.

Given the nature of the students' preconceptions about what constitutes evidence, a question which more tightly structured the students' thinking about the relationship between the experimental results and their ideas about the functions was warranted. With one exception the teacher had not used the specific questions that had been suggested in the strategy (Questions 4 and 5). These questions do appear to more adequately frame the issue: They first articulate aspects of the results and then require the students to explain why these results were obtained. In the one instance where a question of this form was raised (concerning why the isolated embryos were not growing), the two student responses both implied a feeding function for the cotyledon.

The questions included in the instructional strategy for Chapter 5 (7-16 in Table 1) have important functions some of which are not immediately apparent. Our analysis revealed the importance of these questions as well as the ease with which the functions can be foiled by changes in the question or failure to hold the students to the requirements they imply.

For example, Question 8 (Why are the plants in the dark growing so well?) is to be posed after the students have observed the initial growth of plants in both light and dark. When the discussion of the results began in the third lesson (5.3), Ms. Kain simply asked the students for their "observations and why?" As shown in Table 5, responses to this form of the question focused primarily on the differences between the plants in the light and those in the dark. Ms. Kain then refocused the discussion on the plants in the dark. However, her use of the comparative "better" elicited further comments on the differences between the plants in the light and those in the dark.

Ms. Kain finally framed the issue very tightly:

> "What do you attribute the growth to? How is it that they are growing, particularly in the dark? ... Why?"

This elicited among others two very different responses. They referred to some mechanism which would account for the observed growth in the dark. One of these referred to the seed and the cotyledon helping the grass grow. This is an instance of the intended application of an idea from the previous chapter to explain a new result. The second response offering a mechanism referred to the soil as part of the mechanism. Thus, this formulation of the question also served to expose the preconception the strategy was designed to attack.

As indicated in this analysis, question 8 serves at least three important functions:

- It focuses attention on a specific aspect of the result.
- It drives student thinking to consider mechanisms which might account for the observations.
- It brings out two specific mechanisms, one based on anticipated student preconceptions and one based on a previously developed science concept.

TABLE 5

STUDENT RESPONSES RELEVANT TO QUESTION 8:
EXPLANATIONS OF EARLY GROWTH OF PLANTS IN THE DARK*

Type of Response	Form of Question: "Observations and why?" f	Why "ones in dark" are "growing better" f	Why growing in dark (5.3) f	Why growing in dark (5.4) f	Total f	Total %
Suggests mechanism accounting for growth	0	0	2	3	5	21
Cites uncontrolled variable to explain differences between light and dark	3	1	1	2	7	29
Reports observation or prediction of differences only (no explanation)	4	1	2	0	7	29
States that s/he does not know why	0	0	1	2	3	13
Other	1	0	0	1	2	8
Totals	8	2	6	8	24	100

*Based on narratives for task 3 of lesson 5.3 and task 3 of lesson 5.4

It was only when Ms. Kain pressed the students to account for the growth and focused attention away from the comparison between the grass in the light and that in the dark that the questioning played these important functions.

Even better results were obtained in the next lesson (5.4) when Ms. Kain posed the question as suggested and insisted that the students "stick to the question" and address the issue of "Why?" (Table 5). Three different students proposed mechanisms to account for growth in the dark and two more stated explicitly that they didn't know why. Thus, five of the eight responses directly addressed the intended issue.

Our analysis indicates that inadequate framing of another issue contributed to a major problem in student learning. As stated in the results section above, many of the students did not develop the intended understanding of the empirical relation between light and plant growth. While the students became aware that light affected the color and condition of plants, about half of them ended up either believing that the plants did not need light to continue growing or uncertain about this relationship. Central to this problem is the issue of the plants survival in the absence of light as distinct from the effects on the color or health of the plants.

As argued above, in the actual instruction the students' results for the grass experiment of Chapter 5 were ambiguous with respect to survival. It was further argued that this ambiguity was compounded by the students' tendency to focus on their own set up rather than the total array of results and by systematic ambiguity in the use of the term "grow." Another important factor contributing to this problem was that the issue of survival of plants in the dark was not emphasized in class discussions.

The instructional strategy as represented in Table 1 implies that the issue of the plants' survival is the central feature of the results of the

experiment with grass in Chapter 5. This issue is raised explicitly in question 9. It is also explicitly the basis for the discrepant event brought into focus by question 15. However, neither the SCIIS Communities teacher's guide nor the revised guide provided to Ms. Kain indicate the problemmatic nature of this issue or provide suggestions for dealing with it beyond the posing of questions 9 and 15.

Our analysis indicates that the issue of survival was not emphasized in the actual instruction conducted by Ms. Kain. She did pose question 9 during lesson 5.4. Five students responded. One student explained:

> "The sunlight is what gives the plant the green...They'll both survive if you keep feeding them--well, watering and fertilizing them."

Three students supported their opinion that the plants in the dark would die or not keep growing with the essentially circular argument that plants need light. Immediately after this discussion, Ms. Kain posed the next question (10), shifting attention to the color of the grass.

Although students occassionally expressed opinions about it, Ms. Kain never again explicitly raised the issue of survival in discussing the results of Chapter 5. For example, in the final discussion of the results for Chapter 5 (question 11), one student included looking "more alive" and looking "dead" as descriptions of plants in the light and dark, respectively. Ms. Kain included these among the descriptors she listed on the board. However, in summarizing as she posed the next question (12), she stated that the students were "saying that light seems to be important for a healthy plant" (emphasis ours). None of the six responses to question 12--What does light do for plants?--referred to the plants living or dying. Five made reference to the color. Three made analogies to the role of sunlight for humans.

Question 15 in the instructional strategy is intended to challenge the idea that plants get food from the soil.

Question 15: Why did the plants in the dark die and those in the light live when both had the same soil?

After reminding her students that they had kept saying that plants get food from the soil, Ms. Kain attempted to pose the question. She pointed out how the plants had the "same kind of soil" and "both had water," and then added:

> "But this one (a sample from the dark) did not really grow. We're really saying it's on its way down, its' dying or dead. Okay? If some of you had been thinking about the food coming from the soil, why, how can that be? Do you have an explanation for that?"

When she did not get any response, she explained the question again. This time, however, she concluded with, "Why isn't this one doing very well?" She made no reference to plants dying in the dark. None of the four responses she obtained referred to or attempted to account for plants dying in the dark or continuing to live in the light.

Because the issue of survival was not exphasized in Ms. Kain's framing of discussions, the students were not pressed to think about it and had no reason to consider it the major issue. This together with the other factors discussed above help to explain the problem students had in developing the intended understanding of the empirical relation between light and plant growth. Since this relation is the basis for the major challenge to the students' preconceptions in question 15, it is not surprising that the challenge fell flat. The looseness in the posing of this key question and the failure to hold the students to the requirements it implies further help explain this result.

Our analysis indicates that the selection of questions is a very crucial aspect of an instructional strategy. In some cases there appeared to be important gaps in the strategy or questions which were not adequate to the situation. In other instances the teacher did not use questions provided in the

strategy that appeared superior to the ones actually used. In still other instances the teacher used the indicated question but failed to hold students to the requirements it implied. In several cases the teacher failed to recognize when student responses indicated predictable alternative conceptions on the part of the student. Such conceptions include the students' implicit observation theories and explanatory ideals, elements of what Strike and Posner refer to as the students' "conceptual ecology" (1982).

Attacking the Wrong Preconception

The SCIS instructional strategy anticipates that students will hold a preconception concerning the source of food for plants, namely that plants get their food from the soil in the form of water and fertilizer or minerals. This is the preconception attacked by the instructional strategy. The point of exploring the functions of the parts of the seed in Chapter 4 is primarily to provide an alternative conception of the source and nature of food for young plants, namely, the part of the seed referred to as the cotyledon. The point is made that bean seeds in Chapter 4 were germinated without soil and there is an optional activity of growing seeds without soil. Finally, the key discrepant event built into the sequence is the determination in Chapter 5 that grass plants survive in the light but not in the dark, even though both conditions had the same soil. The inability of the soil to sustain plant growth in the absence of light is intended to undermine the preconception of soil as the source of food, preparing the students for the invention of photosynthesis.

As anticipated in the strategy, all but one student asserted on the pretest that fertilizer or water were food for plants. However, on the posttest all but two of the students still included soil or fertilizer along with air,

water and light as food for plants (15) or indicated uncertainty (4) on at least one of the two relevant questions. While many of these students (13) included the cotyledon or referred to photosynthesis as sources of food, these were apparently viewed as additional sources rather than as alternatives.

While the idea that plants get their food from the soil was common among students in the study, this does not seem to be the core of their preconception. The central preconception also seems to be deeper than the idea that water and fertilizer or minerals are food for plants. As discussed by Roth (Roth, et al., 1983), food for plants is conceived by the students as whatever materials are needed and taken in by the plants. Furthermore, their notion of food is additive. If the plants are unable to get certain materials from the soil, other materials such as air and even light may be considered as adequate alternatives.

This preconception of food for plants tended to promote what Hewson (1980) calls "conceptual capture" of the new ideas encountered by the students. Given the additive conception of food for plants as whatever materials the plants take in, the students could simply add the cotyledon as another source of food rather than as an alternative to what constitutes food. Some of the students saw the cotyledon as an "extra" source of water or fertilizer.

Another consequence of this underlying conception of food for plants was that the students could easily escape the trap represented by the intended discrepant event. Light could simply be added as an essential component of plants' food. This preconception also tended to promote conceptual capture of the concept of photosynthesis when it was invented. Several (6) students viewed the food plants made as simply another additional source. Photosynthesis was assimilated by at least some students as a process in which light, water and air were mixed together but each substance maintained its own

identity. Other students interpreted photosynthesis as the name for this mixture. Asked in Chapter 6 why she thought the bean plants in the dark would continue to grow, a student explained that photosynthesis was light, water and air and that "two out of three isn't bad."

Few students came to understand photosynthesis as a process in which food is made out of light, water, and air. Even fewer students understood that green plants have no other source of food. While many factors probably contributed to this result, it appears that the instructional strategy attacks only a superficial aspect of their preconceptions. A more direct attack on the underlying basis for what is considered food for plants appears necessary.

Discussion

This study confirms the findings of other studies (e.g., Nussbaum and Novick, 1982b) that teaching for conceptual change is difficult. More important, it sheds new light on some of the reasons for that difficulty. The instructional sequence was based on a model or generic strategy for conceptual change which seemed well conceived and the specific instructional strategy appeared consistent with it. The teacher had the benefit of a revised guide which made this strategy more explicit and our initial impressions were that the teacher was successfully implementing it. Indeed, our analysis revealed many examples of excellent teaching. However, the limited success of the instruction in bringing about the intended changes in student conceptions led us to look for ways in which instruction went wrong.

Our analysis identified several themes or patterns, ways in which instruction repeatedly seemed problematic. These included:

- Students were often uncertain about empirical generalizations important to the strategy.

- Communication was sometimes hampered by systematic sources of ambiguity.
- Some important issues were not adequately framed through the use of appropriate questions.
- The instruction was in some ways attaching the wrong preconception.

The problems we have illustrated indicate that matching instruction to the conceptual ecology of the students is both essential and difficult. Students' explanatory tendencies, implicit observation theories and preconceptions of specific topics need to be given more attention by researchers, curriculum developers, teacher educators and teachers. Curriculum developers must be aware of predictable alternative conceptions, identify appropriate questions and other moves accordingly, and empirically assess the effects of strategy elements on students. Teachers must also be aware of the alternative conceptions and the intended roles of specific questions so that they can recognize indications of students' alternative conceptions and respond appropriately. Awareness of likely ways of going wrong may help reduce the kinds of problems observed in this study.

The heavy information processing load that this role places on the teacher suggests the importance of incorporating such information into instructional materials. This is not to make the materials teacher proof but rather teachable. Given the best of strategies, the teacher plays a crucial role in the diagnostic use of appropriate questions, in the interpreting of students' responses and taking appropriate actions. In our own work we are exploring the use of text materials (Roth, Anderson and Smith, 1983) and overhead transparencies (Anderson and Smith, 1983a) to assist the teacher in appropriate use of diagnosticly and strategicly important questions.

None of the ways of going wrong discussed above question the SCIIS learning cycle or the underlying view of conceptual change it reflects. The value

of a generic strategy such as the SCIIS learning cycle or Nussbaum and Novick's lies in its prescriptive power. To the degree that it is consistent with the real world of teaching and learning, its use in developing curriculum and planning instruction increases the likelihood that students will learn as intended. While particular strategies might be developed and assessed independently of any explicit generic strategy, the generalizability of such efforts is limited.

While a generic strategy must be sound if its use is to result in effective instruction, a sound generic strategy is not sufficient. A particular strategy may not be an accurate instantiation of the generic strategy or the instruction may not actually implement the strategy. Apart from the issue of fidelity, the particular strategy or instruction may be inadequate in ways that have nothing to do with the adequacy of the generic strategy itself. The examples presented in this paper reflect all four of these possibilities. The models of Strike and Posner (1982) and Hewson (1981) helped identify and interpret these examples and point to other aspects of students conceptual ecology which might be problematic.

In their conclusions, Nussbaum and Novick, (1982a) state:

> In our opinion, the state of the art in cognitive education does not at present offer a widely accepted theory base which could easily facilitate the design of instruction for learning many basic conceptual schemes in school science. p. 20.

While problems such as those described above may not have occurred in their study, it is important to consider other levels of going wrong in assessing a generic strategy and its theory base. Such an assessment should probably be based on productivity over time rather than on the success or failure of a single attempt to apply it. While we would not dispute Nussbaum and Novick's statement, we do think that the currently available theory base does provide an important foundation for ongoing development and research.

Nussbaum and Novick (...id.) conclude with the following recommendation with which we heartily concur:

> That the growing community of practitioners who are looking at SAF's (Student Alternative Frameworks), extend their studies in the direction of designing and testing new instructional sequences based on principles of cognitive accommodation.

More specifically, research and development on instructional sequences for particular topics should seek understanding of the nature of the students' prior knowledge and the effects of the instructional sequence on student behavior and learning. These efforts should address the problems identified with the goal of developing pedogogical knowledge sufficient for reliable achievement of the desired changes in student conceptions.

References

Anderson, C. and Smith, E. Transparencies on Light: Teacher's Manual, (Research Series No. 130). Institute for Research on Teaching, Michigan State University, East Lansing, MI., 1983a.

Anderson, C. W., and Smith, E. L. Children's preconceptions and content area textbooks. In G. Duffy, L. Roehler, and J. Mason (Eds.), Comprehension Instruction: Perspectives and Suggestions. New York: Longman, Inc., 1983b, 187-201.

Atkin, M. and Karplus, R. Discovery or Invention? The Science Teacher, September, 1962, 45-51.

Helm, H. and Novak, J. (editors) Proceedings of the International Seminar on Misconceptions in Science and Mathematics, June 20-22, 1983, Cornell University, Ithaca, N.Y.

Hewson, P. W. A case study of the effect of metaphysical commitments on conceptual change in science. Paper presented at the annual meeting of the American Educational Research Association, April, 1980.

Hewson, P. W. A conceptual change approach to learning science. European Journal of Science Education, 1981, 3 (4), 383-396.

Knott, Robert; Lawson, Chester; Karplus, Robert; Thier, Herbert D.; and Montgomery, Marshall. Communities. Rand McNally, Chicago, 1978.

Kuhn, Thomas. The Structure of Scientific Revolutions. University of Chicago Press, Chicago, 1962.

Nussbaum, J. and Novick, S. A study of conceptual change in the classroom. Paper presented at the meeting of the National Association for Research in Science Teaching, April, 1982a.

Nussbaum, J. and Novick, S. Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy. Instructional Science, 1982, 11, 183-200b.

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 1982, 66 (2), 211-228.

Roth, K. I.; Anderson, C. W. and Smith, E. L. Food for Plants Teacher's Guide. Institute for Research on Teaching, Michigan State University.

Roth, K. I., Smith, E. L., and Anderson, C. W. Students' conceptions of photosynthesis and food for plants. Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada, April, 1983.

Smith, E. and Anderson, C. The effects of teachers guides on teacher planning and classroom instruction in activity based science. Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada, April, 1983a.

Smith, Edward L. and Anderson, Charles W. Plants as producers: A case study of elementary science teaching. (Research Series No. 127), Institute for Research on Teaching, Michigan State University, East Lansing, MI., 1983b.

Strike, K.A. and Posner, G.J. "Conceptual Change and Science Teaching." European Journal of Science Education, 1982, 4(3), 231-240.

Toulmin, Stephen. Human Understanding. Princeton, New Jersey, Princeton University Press, 1972.

Viennot, L. "Spontaneous Reasoning in Elementary Dynamic." European Journal of Science Education, 1, (2), 205-221.